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Shear Resistance of Steel Stud Wall Panels: a Summary Report

Thomas S. Tarpy Jr.

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SHEAR RESISTANCE OF STEEL STUD WALL PANELS:

A Summary Report

by Thomas S. Tarpy, Jr.[1]

Introduction

The American Iron and Steel Institute conducted a series of tests over an extended period of time to determine the in-plane shear resistance of sheathed steel stud wall assemblies. The study was directed specifically at determining the in-plane shear resistance and deflections for a wide range of different types of wall construction commonly encountered in practice.

The overall objectives of the test program were: 1) to determine the effect of different construction techniques and anchorage details on the in-plane shear resistance of steel stud shear walls with different types of sheathing material, 2) to determine the load level at which the sheathing material first experiences damage, and 3) to determine allowable shear values for design for vertical diaphragms with different sheathing material on steel-framed wall assemblies.

Test Program

The test program was conducted at Vanderbilt University in accordance with ASTM E564(2) and consisted of testing different types of wall panel construction and anchorage techniques using both static uni-directional loading and cyclic loading procedures. ASTM E564 is a static test method for determining the shear resistance of framed walls for buildings. The number of actual tests included in each wall type was a function of the ASTM E564 requirements. Basically, this standard requires that if the results of two different tests for a given wall type construction differ by more than 10%, a third test is run and the shear resistance for the wall type is the mean of the lower two values obtained from the three test results. The typical wall test method configuration is shown in Figures 1 and 2.

The actual wall construction and anchorage details for each wall type, as well as the type of loading condition, are shown in Table 1. Wall Type O was not used for clarity. The parameters considered in this study are:

(a) the effect of wall panel anchorage details - Wall Types A, B, E, H and K

(b) the effect of gypsum wallboard thickness - Wall Types H and I

[1]Senior Structural Engineer, Stanley D. Lindsey & Associates, Ltd., Nashville, Tennessee; Research Associate Professor, Department of Civil Engineering, Vanderbilt University, Nashville, Tennessee.

(c) the effect of different sheathing materials - Wall Types G, H, I and J

(d) the effect of static versus cyclic loading conditions - Wall Types B, D, E and H

(e) the effect of gypsum wallboard attachment spacing - Wall Types A, C and D

(f) the effect of a diagonal corner brace - Wall Types A and F

(g) the effect of anchoring the wall panel through transverse floor joists - Wall Types L, P and Q

(h) the effect of plywood or gypsum exterior sheathing in place of gypsum wallboard as a diaphragm material - Wall Types L, M and N

(i) the effect of using fillet welds instead of self drilling screws to attach the studs to the runner tracks - Wall Types A and L

(j) the effect of stud spacing - Wall Types A and R

Construction of Wall Panels

Wall Types A through F were constructed of 3-1/2 inch web by 1-1/2 inch flange by 1/2 inch lip galvanized structural steel "C" studs with a base metal thickness of 0.032 inch (nominal 20 gage). The steel studs were spaced 24 inches on centers and attached to 3-5/8 inch web by 1-1/2 inch flange galvanized structural steel-runner track with #10 x 1/2 inch Low Profile Head Screws. The base metal thickness of the runner track was 0.035 inches (nominal 20 gage). The measured yield strength of the studs for three coupons cut longitudinally from the web ranged from 52 ksi to 55 ksi with a mean value of 53 ksi (40 ksi minimum yield). The measured yield strength of the runner track for three coupons cut longitudinally from the web ranged from 49 ksi to 51 ksi with a mean value of 50 ksi (33 ksi minimum yield).

Wall Type G was constructed with stucco applied on metal lath. The total thickness of the stucco layer was 7/8 inch thick and was spread evenly on 3.4-3/8 inch rib expanded metal lath. The lath was fixed to the studs and track with 5/8 inch tee-shaped drive pins at 3.75 inches on centers. The stucco was trowelled onto the metal lath using a standard three-coat process. The stucco mix design consisted of:

1. 1st coat - 94 lbs. of cement, 50 lbs. of lime, 6 cu. ft. of sand,

2. 2nd coat - 94 lbs. of cement, 50 lbs. of lime, 6 cu. ft. of sand,

3. 3rd coat - 2 volumes of lime, 1 volume of gauging plaster.

The approximate thickness for each coat was 3/8 inch, 3/8 inch, and 1/8 inch for the first, second and third or finishing coat, respectively.

A minimum curing time of 3 days was allowed between each coat application. The construction procedure followed was that recommended by the Uniform Building Code (16).

Wall Types H and I and the cyclic loading panels for Wall Types B, D and E were constructed of 3-5/8 inch web by 1-5/8 inch flange by 1/2 inch lip painted structural steel studs with a base metal thickness of 0.037 inch (nonimal gage). The steel studs were spaced 24 inches on centers and attached to 3-13/16 web by 1-1/4 inch flange painted structural steel-runner track with #10 x 1/2" Low Profile Head Screw. The base metal thickness of the runner track was 0.037 inches (nominal 20 gage). The measured yield strength of the studs for three coupons cut longitudinally from the flange ranged from 50 ksi to 54 ksi with a mean value of 52 ksi (37 ksi minimum yield). The measured yield strength of the runner track for three coupons cut longitudinally from the web ranged from 42 ksi to 48 ksi with a mean value of 45 ksi (37 ksi minimum yield).

Wall Type J was constructed to represent either exterior or interior stud wall construction. Portland cement plaster, 7/8 inch thick was trowelled on to 3.4-3/8 inch rib expanded metal lath using a standard three coat process. The lath was fixed to the studs with #8 x 1/2 inch Pan Washer Head Screws at 7-3/4 inches on centers. The plaster mix design consisted of:

1. First coat - 1 volume cement, 20 lbs. lime, 4 volumes sand;

2. Second coat - 1 volume cement, 20 lbs. lime, 5 volumes sand; and

3. Third coat - 1 volume cement, 1 volume lime, 3 volumes sand.

The approximate thickness for each coat was 3/8 inch, 3/8 inch, and 1/8 inch for the first, second, and third coat, respectively. A minimum curing time of three days was maintained between each coat application. The construction procedure followed was that recommended by the Uniform Building Code (16).

Wall Types K through R were constructed using 3-5/8 inch web by 1-5/8 inch flange by 3/8 inch lip painted structural steel "C" studs with a base metal thickness of 0.0359 inches (nominal 20 gage). The studs were attached to 3-13/16 inch web by 1-1/2 inch flange painted structural steel runner track, also with a base metal thickness of 0.0359 inches. Unpunched steel floor joists with a base metal thickness of 0.0598 inches (nominal 16 gage) measuring 7-1/4 inch web by 1-5/8 inch flange by 9/16 inch lip were used at the base of Wall Types P and Q. The measured yield strength of the studs for three coupons cut longitudinally from the web ranged from 29.5 ksi to 30.6 ksi (mean of 30.1 ksi) with an average base metal thickness of 0.042 inches. Coupon tests on the runner track produced a measured yield strength range of 22.4 ksi to 26.2 ksi (mean of 24.3 ksi) and a mean thickness of 0.039 inches. The range of the yield strength of the joists tested was 59.9 ksi to 61.1 ksi (mean of 61.0 ksi). The joists had a mean base metal thickness of 0.061 inches. The minimum specified yield strength of the studs and runner tracks was 19.8 ksi. The floor joists used had a minimum specified yield strength of 30.0 ksi.

The basic steel frame panel anchorage for the attachment of the wall panel to the load frame was the hot rolled structural steel clip angle. The clip angles were attached to the steel-stud members at four foot centers along the base and bolted through the runner track, wood shim, and load frame base channel. This basic attachment detail was used on Wall Types A, C, D, F, G, L, M, N and R. Wall Type E was selected to determine if the same shear resistance and damage threshold load level could be obtained without the added cost associated with these angles. For this case, 3/8 inch diameter x 3 inch long zinc plated Hex Head Bolts and 1 inch outside diameter zinc plated washers located at four feet were used to attach the wall panel to the test frame. The major difference between the bolt and washer attachment and the basic clip angle attachment is the positive attachment to the vertical stud obtained with the clip angle and the difference in the amount of bearing contact area obtained between the angle leg and the washer at the attachment of the runner track to the test frame. Wall Type B construction was the same as Wall Type E except the clip angles were included at the corners to increase the contact area and to resist uplift at the end vertical stud. A cold formed, 16 gage, clip angle was used in Wall Type K to determine if sufficient anchorage and shear rigidity could be obtained with the expense of the hot rolled angle. Wall Types H, I and J used the standard powder activated fastener commonly used in construction and sized based on the applied forces. The base anchorage for Wall Types P and Q were special configurations to simulate load transferred through transverse floor joists - either fastened or welded.

The gypsum wallboard was attached to the steel stud frames with self-drilling screws of a size, length and spacing as noted in Table 1. The gypsum wallboard seams were caulked and taped and allowed to cure at least 24 hours before the wall panel was tested. Gypsum sheathing and plywood seams were left open. The construction details for each wall type are shown in Figures 3 through 19, respectively.

Test Set-Up

A structural steel joist member with reinforcing plates and a load bearing block was attached along the top of the wall panels at the point(s) of loading to uniformly distribute the load along the wall and to prevent localized failure of the panel at the point(s) of loading. The detail is shown in Figure 20. By attaching the steel joist to the wall panels in this manner, the laboratory conditions represented as closely as possible actual field installation and loading conditions for a roof and/or floor attachment.

Prior to starting a test, displacement indicating gages were mounted on the test frame at the locations shown in Figure 2. The horizontal gages at the lower right, No. 4, and at the lower left, No. 8, measured the slippage of the wall panel in the test frame. The two vertical gages, No. 3 and No. 5, measured panel rotation and Gage No. 1, at the upper right, measured the horizontal or lateral displacement of the panel. This displacement includes the effects of:

a) Shear and bending deformation of the test panel,

b) Slippage between the wall panel and the test frame, and

c) Possible deformations in the test frame.

In addition to the gages on the wall panel, Gages No. 6 and No. 7 corresponding to the vertical Gages No. 5 and No. 3 measured any movement in the test frame at the corner attachment points. Gage No. 2, shown at the point of loading on the upper left of the figure, was used only as a backup for Gage No. 1 with static loading conditions, and for measuring the horizontal panel deformation opposite the load point on the right for cyclic loading conditions.

Test Procedure

(a) Static Loading

The loading sequence consisted of applying an initial load of approximately ten percent of the estimated ultimate load carrying capacity of the wall panel to the top of the wall panel using a hydraulic jack/load-cell/digital-strain-indicator. This load was held for two minutes to "set" the wall panel connections and was then removed. The wall panel was allowed to fully recover and the displacement measuring devices were set to zero to begin the test at this zero load-deflection condition. The load was then applied incrementally to the wall panel and displacement measurements recorded at each interval following a two-minute hold period. At load levels of approximately one-third and two-thirds of the estimated ultimate load carrying capacity of the wall panel, the load was fully removed, and the wall panel recovery was recorded after a five-minute hold period. The load was then re-applied to the next higher increment above the back-off load. Loading continued in this manner until the wall panel was no longer capable of holding additional load. The last load, held for two minutes with displacement measurements recorded, was defined as the ultimate load. The typical load-displacement condition for static loading is shown in Figure 21a.

(b) Cyclic Loading

The cyclic loading sequence consisted of applying an initial load of approximately ten percent of the estimated ultimate load carrying capacity of the wall panel to the wall panel in one direction. This load was held for two minutes to set the wall panel connections and was then removed. The wall panel was allowed to fully recover before beginning the test at this zero load-deflection condition. The load was then applied incrementally to the right or positive direction, in the direction of preload, to a previously determined load interval.

Displacement measurements were recorded immediately upon reaching the interval load value. After recording the displacements, the load was released and the wall allowed to fully recover at which time another set of displacement readings were obtained. The load was then applied to the left, in the opposite or negative direction from before, until the same load level was obtained. Displacement measurements were recorded and the load fully released. At this zero load, additional displacement measurements were obtained. This process completed one full cycle of the test for a given load interval. The loading sequence continued as before for four additional cycles at the same load interval; the only difference was that the zero load-displacement measurements were not recorded. Upon completion of the fifth cycle, the load was applied in the positive direction to the next higher load interval and the previously described loading sequence repeated for five full cycles. Loading continued in this manner for increasing load intervals until the wall panel was no longer capable of holding additional load. The ultimate load was the last load for which at least one complete cycle was obtained with complete displacement measurements. The load-displacement condition for cyclic loading is shown in Figure 21b.

Analysis of Test Results

The information obtained from the test data are load-deflection curves, ultimate shear strength, shear stiffness, and damage threshold load level. The load-deflection curves are plots of the applied load versus the measured total panel deflection.

The total panel deflection, Δ_T is defined as either:

$$\Delta_T = \Delta_1 - \Delta_4 \text{ (in.)}$$

for loading in the positive direction, or

$$\Delta_T = \Delta_2 - \Delta_8 \text{ (in.)}$$

for loading in the negative direction

where Δ_1, Δ_2, Δ_4 and Δ_8 are measured deflections (in.) at gage locations 1, 2, 4, and 8, respectively, as shown in Figure 2.

The net deflection is that deflection due to shear only and is defined as:

$$\Delta_N = \Delta_T - \frac{a}{b}(\Delta_3 - \Delta_7 + \Delta_5 - \Delta_6) \text{ (in.)}$$

where Δ_3, Δ_5, Δ_6, and Δ_7 are the deflections measured at gage locations 3, 5, 6 and 7 respectively, a is the height and b is the length of the wall panel.

The ultimate shear strength, S_u, of the wall panel is defined as:

$$S_u = P_u/b \quad \text{(lb./ft.)}$$

where P_u is the ultimate load carrying capacity of the wall panel (lb.) and b is the length of the wall panel (ft.).

The total shear stiffness, G'_T, is determined from the load-deflection curve at a value equal to or less than the proportional limit. A suggested reference load level, P, by ASTM E564 is one-third the ultimate load. If this value exceeds the proportional limit, P is chosen to be equal to the proportional limit. The total shear stiffness is defined as:

$$G'_T = \frac{a}{b} \times \frac{P}{\Delta_T} \quad \text{(lb./in.)}$$

where P is the load (lb), and Δ_T is the corresponding total deflection (in.) at P for displacement in either the positive or negative direction, a is the height of the wall panel (ft.), and b is the length of the wall panel (ft.).

The net shear stiffness, G'_N, is defined by AISI (3) as:

$$G'_N = \frac{a}{b} \times \frac{(P)}{\Delta_s} \quad \text{(lb./in.)}$$

where P is the suggested reference load level and Δ_s is the corresponding shear displacement defined as:

$$\Delta_s = \Delta_N - \Delta_B \quad \text{(in.)}$$

where Δ_N is the net deflection obtained from the load-deflection curve at the suggested reference load and Δ_B is the bending deflection considering the wall panel to be a cantilever beam loaded at its free end. The bending deflection can be determined by:

$$\Delta_B = \frac{Pa^3}{3EI} \quad \text{(in.)}$$

where P is the reference load, E is the modulus of elasticity of the steel studs and I is the moment of inertia considering only the perimeter members of the wall panel frame.

The damage threshold load level, P', is based on visual observation, and is defined as the load level at which damage to the sheathing material occurred. For gypsum wallboard material, this value is the load at which the paper just begins to tear. The P' values are subjective and are based on the observations of several individuals involved in the testing.

Discussion of Results

The experimental results for the individual wall panel tests as well as the average values of the tests for Wall Types A through R are summarized in Table 2. The average values shown correspond to the recommended acceptance criteria of ICBO (1) for testing of wall panels and not that of ASTM E564 mentioned earlier in the paper. Basically, this criteria states that "except for the inpact test, three tests of each type are required with none varying more than 15 percent from the average of the three, unless the lowest test value is used. The average result based on a minimum of five tests may be used regardless of the variations. The results of two tests may be used when the higher value does not exceed the lower value by more than 5 percent and the lower value is used with the required factors of safety. The values shown for the cyclic tests are the average values of the five cycles in the positive direction. For a detailed discussion of the individual panel descriptions, test set-ups, manner of testing, observations, all test readings and load deflection curves, one should refer to References 4 through 11.

All wall types tested experienced the same basic type of failure. The initial sign of distress was the wall base runner tracks deforming around the anchorage device (either clip angle, powder actuated fastener, or washers) at the uplift corner of the wall identified by Location 5 in Figure 2. For panels with gypsum sheathing, cracking of the gypsum sheathing occurred at the same location, extending from the corner fasteners to the edge of the wallboard. The track deformation and tearing of the gypsum increased until the wall panel was no longer able to carry additional load.

Wall Type A is used as the base reference in the following discussion of the effect of various parameters on the shear resistance of the wall panel where possible. This reference was chosen because of the extensive amount of data available on Wall Type A with variable aspect ratios (4).

(a) Effect of Wall Panel Anchorage

The wall panel anchorage effect on the shear strength is seen by comparing Wall Types A, B, E, H and K. The elimination of the clip angles at the interior locations (Type B) had little effect on the shear strength. This was due to the stiffening effect the corner angles furnish to the runner track and end vertical stud. A 23% decrease in shear strength resulted with the substitution of bolt and washers (Type E) in place of the corner angles. The use of several powder actuated fasteners (Type H) near the end stud, and as close to the edge of the track as possible, had a similar restraining effect as the angles for Wall Type A and B, thus, reducing the track bending around the anchoring devices. This restraining effect existed as long as the fastener embedment was sufficient against pullout. The type of interior anchorage had little effect on the shear resistance. Wall Type K, with light gage steel clip angles and powder actuated fasteners located more closely towards the centerline of the track experienced earlier pullout of the powder-actuated fasteners than Wall Type H without the clip angles. A 24% decrease in shear strength resulted from using the light gage clip angle attachment, while only a 17% decrease resulted from using powder activated fasteners instead of the hot rolled structural steel angle in Wall Type A.

The shear stiffness appears to be highly dependent upon the corner anchorage of the wall. The use of corner angles for Wall Types A and B resulted in essentially the same value for total shear stiffness. The elimination of the angles resulted in a 60% decrease for Type E and a 53% decrease for Type H. This was because of the larger wall panel deformations that occurred when the corner angles are removed.

The influence of corner anchorage is also apparent in the damage threshold load level. The bolt and washer anchorage resulted in a 17% decrease in load level. The use of light gage clip angles resulted in a 42% decrease in the damage threshold load level. The use of powder actuated fasteners resulted in a negligible increase in load level. A

98% increase in total shear stiffeners was noted for Wall Type K over Wall Type H at the reference load level due to the addition of light-gage steel clip angles at the corner. All anchorage types resulted in a decrease in total shear stiffness over that of Wall Type A.

(b) Effect of Gypsum Wallboard Thickness

The effect of using two layers of 5/8 inch gypsum wallboard instead of one layer of 1/2 inch gypsum wallboard for the same base anchorage is seen by comparing Wall Types H and I. The use of two layers resulted in an increase of 16% in shear strength and a 15% decrease in total shear stiffness. The increase in shear strength is attributed to the additional fasteners used to attach the second layer of wallboard over the first layer. A 32% increase in damage threshold load level resulted from the use of two layers of wall board over that with one layer.

(c) Effect of Different Sheathing Material

The effect of different sheathing materials is noted by comparing Wall Types G, H, I and J for the same anchorage. A 16% increase in ultimate shear strength was obtained by using either cement plaster or two layers of gypsum wallboard over a single layer of gypsum wallboard. Stucco resulted in a 26% increase in shear strength. An increase of 166% in total shear stiffness was obtained for the plaster walls over the gypsum wallboard. This large increase in shear stiffness is due to the increase in strength of the cement plaster over that of gypsum.

The damage threshold load level is highly dependent upon the exterior sheathing. The use of cement plaster or stucco resulted in a fairly rigid wall system without noticeable cracking of the surface.

(d) Effect of Static Versus Cyclic Loading

The effect of the type of loading on the wall panels is seen by comparing Wall Types B, D, E and H. In all cases the ultimate shear strength was less than or equal to the value obtained for static loading. This decrease was 38% for Type D, 8% for Type E and 19% for Type H. For Type B, the ultimate shear strength was independent of the type of loading. The corresponding effect of cyclic loading on shear stiffness was a 152% increase for Type B, 231% for Type D, 88% for Type E and 142% for Type H. This increase was apparently due to the smaller total deflections recorded for the cyclic loading condition than for the static loading condition. The stiffening effect of the corner angles was still apparent for Type B independent of loading.

Cyclic loading had a weakening effect on the damage threshold load level for all wall panels except Wall Type B. The decreased damage threshold load levels ranged from 32% for Type H to only 10% for Type E. The range of load levels appears to be related to the degree of corner anchorage rigidity.

(e) Effect of Gypsum Wallboard Attachment Spacing

Comparing Wall Types A, C and D, it is noted that the ultimate shear strength is affected by the gypsum wallboard fastener spacing. A decrease in the fastener spacing from 12 inches on centers (Type A) to 6 inches on centers around the perimeter (Type C) resulted in a 78% increase in ultimate shear strength. A 50% increase in ultimate shear strength was obtained by reducing the fastener spacing to 6 inches on centers over 24 inches at the corners only (Type D).

The damage threshold load level at initial cracking of the sheathing material and the corresponding total deflection value are dependent upon wallboard fastener spacing. A decrease in perimeter fastener spacing helped restrain wall panel rotation and thus total deflection from that of the bolt and washer anchorage. This resulted in an increase in the load level before damage to the sheathing of 69% and 38% for Wall Types C and D, respectively, over Wall Type A.

(f) Effect of a Diagonal Corner Brace

The addition of the diagonal corner brace in Wall Type F resulted in a 13% reduction in load level at initial tearing from that of Wall Type A due to concentration of stresses around the perimeter defined by the brace and edge of the wall. The addition of the corner brace resulted in an increase in ultimate shear strength of 20%.

(g) Effect of Anchoring Through Floor Joists

The effect of wall panel base anchorage through floor joists is seen by comparing Wall Types L, P and Q. The only variation between these wall types was in the method of wall panel anchorage. Failure of the welds in the floor joist system of Wall Types P and Q, and the subsequent deformations of the joists and track sections, exaggerated the rotation and total deflection of these wall panels. This large panel rotation caused weakening of the wall panel and early failure.

The total ultimate shear strength of Wall Type L is 17% greater than Wall Type P and 26% greater than Wall Type Q. This is to be expected since Wall Type L is more rigidly attached without being anchored through floor joists. Additionally, Wall Type L resulted in a significantly greater shear stiffness than either Wall Types P or Q but with approximately the same damage threshold load level.

(h) Effect of Diaphragm Material

Wall Types L, M and N were constructed and anchored identically, except for the diaphragm material used on one side of the wall panel. Wall Type M, covered with exterior gypsum sheathing on one side and gypsum wallboard on the other side, resulted in a 37% decrease in ultimate shear strength of that of Wall Type L which was covered with gypsum wallboard on both sides. Wall Type N, constructed with construction grade plywood on one face and gypsum wallboard on the other face resulted in a 26% increase in ultimate shear strength.

The total shear stiffness in Wall Type M was essentially the same as that of Wall Type L while that of Wall Type N was 7% less. A reduction of 24% in initial damage threshold was obtained using gypsum sheathing in place of gypsum wallboard.

(i) Effect of Stud Attachment

The effect of fillet welding the stud to the edge of the runner track (instead of using self drilling screws) is seen by comparing Wall Types A and L. Wall Type L was identical to Wall Type A in all other aspects of construction and anchorage.

The ultimate shear strength was 13% greater for fillet welds over screws, while the gypsum damage threshold of Wall Type L was 13% less than that of Wall Type A. The shear stiffness for Wall Type L was 28% less than Wall Type A.

(j) Effect of Stud Spacing

The effect of stud spacing is seen by comparing Wall Types A and R. Wall panels constructed with the studs at 16 inches on centers instead of 24 inches on centers, but with the same wallboard fastener spacing, provide more points for the transfer of the load between the diaphragm material and the wall panel steel stud frame. This resulted in a 27% increase in ultimate shear strength due to the closer stud spacing but with an 8% decrease in damage threshold load level. The total shear stiffness of Wall Type R was 60% less than Wall Type A by virtue of its larger total deflection at the lower load levels.

Conclusions

The results obtained from this investigation indicate that the wall panels, framed with "C" shaped structural steel studs, and constructed and anchored as reported herein, can resist lateral in-plane shear loads when used as vertical shear wall diaphragms in buildings. However, it is the opinion of the writer that certain design and construction recommendations should be followed. These recommendations and conclusions are as follows:

(a) A rigid attachment should be designed to connect the wall panel to the floor or roof framing systems if a resultant uplift force exists (i.e. the design dead load is not sufficient to prohibit overturning of the wall). This attachment could be with the corner clip angle detail used herein or by some equivalent means.

(b) A proper transfer of the gravity and lateral load through the floor joists is necessary to prevent local joist failure. This could be accomplished with additional steel plates or other similar means.

(c) Welding the studs to the track is equivalent to using self-drilling screws.

(d) The wall panel diaphragm material should possess at least the shear modulus of the gypsum wallboard material.

(e) Adequate construction precautions must be maintained to protect the gypsum wallboard from the effects of moisture.

(f) The use of plywood sheathing, stucco or plaster increases the shear resistance of the wall panel over that with gypsum wallboard.

(g) Decreasing the stud spacing only slightly increases the shear strength.

(h) For design purposes, a minimum factor of safety of 2.0 is recommended to determine the design shear strength for steel-stud framed wall panels constructed as reported herein. This minimum value results in a design load level below the damage threshold load level.

The recommended design values for allowable shear strength of vertical diaphragms of plywood, plaster or gypsum board on steel-framed wall assemblies are shown in Table 3 for possible inclusion in the various national building codes. This table format is similar to ones that already exist for vertical diaphragms constructed using wood stud framing and various sheathing materials (16). The allowable shear value shown is based on a factor of safety of 2.0 and uses the minimum test load from either the ultimate load based on strength or the load based on a maximum recommended code deflection criteria of 0.5 inches.

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15. Tarpy, T.S., and Girard, J.D., "Shear Resistance of Steel Stud Wall Panels," Proceedings of the Sixth International Specialty Conference on Cold-Formed Steel Structures, held at St. Louis Missouri, November, 1982, pp. 449-465.

16. Uniform Building Code, 1982 Edition, International Conference of Building Officials, Whittier, California, Part X, Chapter 47, pp. 648-670.

Appendix II -- Notation

a	=	Height of the wall panel (ft)
b	=	Length of the wall panel (ft)
E	=	Modulus of elasticity of steel (ksi)
G'_N	=	Shear stiffness based on net deflection (lb/in)
G'_T	=	Shear stiffness based on total deflection (lb/in)
I	=	Moment of inertia of steel stud frame (in^4)
P	=	Load level for determining the shear stiffness (lb)
P_u	=	Ultimate load (lb)
P'	=	Damage threshold load level at initial cracking (lb)
S_u	=	Ultimate shear strength (lb/ft)
Δ_i	=	Deflection at displacement measuring location i (in)
Δ_N	=	Net deflection (in)
Δ_B	=	Bending deflection (in)
Δ_s	=	Shear deflection (in)
Δ_T	=	Total deflection (in)

TABLE 1
WALL PANEL CONSTRUCTION

WALL TYPE (PANEL SIZE) LOADING COND.	TYPE/THICKNESS OF DIAPHRAGM MAT'L; WALL CONSTRUCTION	DIAPHRAGM ATTACHMENT	STUD SPACING	STUD ATTACHMENT	WALL ANCHORAGE
Type A (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8x3-1/4"LG @48" o.c. with 3/8" ϕ Hex Head Bolts
Type B (8'-0Hx12'-0L) Static/Cyclic	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8x3-1/4" LG @ Ends with 3/8" ϕ Hex Head Bolts, 3/8"ϕ Hex Head Bolts w/1" O.D. Washer @ Mid-point
Type C (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @6" o.c. Perimeter, Balance @ 12" o.c.	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts
Type D (8'-0Hx8'0L) Static/Cyclic	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track & 6" o.c. for 24" @ corners	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts

TABLE 1 (CONTINUED)
WALL PANEL CONSTRUCTION

WALL TYPE (PANEL SIZE) LOADING COND.	TYPE/THICKNESS OF DIAPHRAGM MAT'L; WALL CONSTRUCTION	DIAPHRAGM ATTACHMENT	STUD SPACING	STUD ATTACHMENT	WALL ANCHORAGE
Type E (8'-0Hx8'-0L) Static/Cyclic	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	3/8"ϕ Hex Head Bolts with 1" Washer @ 48" o.c.
Type F (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c.	20 gage C-stud 24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts
Type G 8'-0Hx8'-0L) Static	7/8" Portland Cement Lime Stucco on 3.4-3/8" Rib Expanded Metal Lath Three-Coat Process	5/8" "T" Drive Pin @ 3.75" o.c.	3-1/2" 20 gage C-stud 24" o.c.	#8x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3x3/8-1/4"(LG 48" o.c. with 3/8" ϕ Hex Head Bolts
Type H (8'-0Hx8'-0L) Static/Cyclic	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	9/64"ϕ x1-1/4" Powder Actuated Fasteners @ 6" o.c.
Type I (8'-0Hx8'-0L) Static	5/8" Gypsum Wallboard Two-Ply Each Face	Base-Ply #6x1" Bugle Head Screws @24" o.c. Face-Ply #6x1-3/8" Bugle Head Screws @ 12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	9/64"ϕ x1-1/4" Powder Actuated Fasteners @ 6" o.c.

TABLE 1 (CONTINUED)
WALL PANEL CONSTRUCTION

WALL TYPE (PANEL SIZE) LOADING COND.	TYPE/THICKNESS OF DIAPHRAGM MAT'L; WALL CONSTRUCTION	DIAPHRAGM ATTACHMENT	STUD SPACING	STUD ATTACHMENT	WALL ANCHORAGE
Type J (8'-0Hx8'-0L) Static	7/8" Cement Plaster on 3.4-3/8" Rib Expanded Metal Lath Three-Coat Process Each Face	#8x1/2" Pan Washer Head @7-3/4" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	9/64"ϕ x1-1/4" Powder Actuated Fasteners @6" o.c.
Type K (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	16 gage clip angle @ 24" o.c. with 9/64"ϕ x1-1/4" LG Powder Actuated Fasteners @6" o.c.
Type L (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	1/8"x1" Fillet Weld Each Side	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts
Type M (8'-0Hx8'-0L) Static	1/2" Exterior Gypsum Sheathing & 1/2" Gypsum Wallboard Single-Ply Opposite Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	1/8"x1" Fillet Weld Each Side	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts

TABLE 1(CONTINUED)
WALL PANEL CONSTRUCTION

WALL TYPE (PANEL SIZE) LOADING COND.	TYPE/THICKNESS OF DIAPHRAGM MAT'L; WALL CONSTRUCTION	DIAPHRAGM ATTACHMENT	STUD SPACING	STUD ATTACHMENT	WALL ANCHORAGE
Type N (8'-0Hx8'-0L) Static	1/2" Construction Grade Plywood & 1/2" Gypsum Wallboard Single-Ply Opposite Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	1/8"x1" Fillet Weld Each Side	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts
Type P (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @24" o.c.	1/8"x1" Fillet Weld Each Side	Track Welded to Floor Joists per Details & Bolted to Load Frame
Type Q (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12 o.c. Studs & Track	20 gage C-stud 24" o.c.	1/8"x1" Fillet Weld Each Side	Track Fastened to Floor Joists per Details & Bolted to Load Frame
Type R (8'-0Hx8'-0L) Static	1/2" Gypsum Wallboard Single-Ply Each Face	#6x1" Bugle Head Screws @12" o.c. Studs & Track	20 gage C-stud @16" o.c.	#10x1/2" Low Profile Head Screws Each Side Top & Bottom	L3x3z3/8x3-1/4" LG @48" o.c. with 3/8"ϕ Hex Head Bolts

TABLE 2
SUMMARY OF TEST RESULTS

WALL TYPE (PANEL SIZE) LOADING	TEST NO.	TEST LOADS[1] ULTIMATE (lb.)	TEST LOADS[1] CODE DEFL. (lb.)	TEST LOADS[1] TEARING (lb.)	ALLOWABLE[2] SHEAR STRENGTH (lb./ft.)	DEFLECTION[3] NET (in.)	DEFLECTION[3] TOTAL (in.)	SHEAR STIFFNESS[4] NET (lb./in.)	SHEAR STIFFNESS[4] TOTAL (lb./in.)
Type A	A1	3,200	2,800	2,400	175	0.120	0.117	8,900	9,200
(8'-0Hx8'-0L)	A2	3,400	2,900	2,800	181	0.123	0.114	9,700	10,500
Static	A3	3,000	2,500	2,800	156	0.100	0.090	10,000	11,100
	A4	2,600	2,600	2,200	163	0.063	0.077	11,750	11,300
	A5	2,600	2,400	2,200	150	0.074	0.100	11,700	8,700
	A6	3,400	2,800	2,000	175	0.084	0.112	13,500	10,100
AVERAGE		3,000	2,700	2,400	167	0.094	0.102	10,900	10,200
Type B	B1	4,500	4,300	3,600	179	0.045	0.080	33,300	12,500
(8'-0Hx12'-0L)	B2	4,500	-	3,900	188	0.032	0.078	31,300	12,800
Static	B3	4,500	-	2,400	188	0.052	0.065	19,200	15,400
AVERAGE		4,500	4,300	3,300	185	0.043	0.074	27,900	13,600
Type B	B1	4,800	-	3,600	200	0.004	0.033	238,600	32,800
(8'-0Hx12'0L)	B2	4,200	-	3,600	175	0.020	0.026	46,700	35,800
Cyclic									
AVERAGE		4,500	-	3,600	188	0.012	0.030	46,700	34,300
Type C	C2	5,600	4,700	4,200	293	0.123	0.191	15,200	9,800
(8'-0Hx8'-0L)	C3	5,100	4,300	3,900	269	0.104	0.182	16,300	9,300
Static									
AVERAGE		5,350	4,500	4,050	281	0.114	0.187	15,800	9,600

TABLE 2 (CONTINUED)
SUMMARY OF TEST RESULTS

WALL TYPE (PANEL SIZE) LOADING	TEST NO.	TEST LOADS[1] ULTIMATE (lb.)	CODE DEFL. (lb.)	TEARING (lb.)	ALLOWABLE[2] SHEAR STRENGTH (lb./ft.)	DEFLECTION[3] NET (in.)	TOTAL (in.)	SHEAR STIFFNESS[4] NET (lb./in.)	TOTAL (lb./in.)
Type D	D1	3,900	3,600	3,300	225	0.097	0.132	13,400	9,800
(8'-0Hx8'-0L)	D2	4,500	3,800	3,300	238	0.065	0.134	23,100	11,200
Static	D3	5,100	3,900	3,300	244	0.109	0.149	15,600	11,400
AVERAGE		4,500	3,800	3,300	236	0.090	0.138	17,400	10,800
Type D	D1	2,800	-	2,400	175	0.033	0.023	27,700	40,300
(8'-0Hx8'-0L)	D2	2,800	-	2,400	175	0.046	0.030	19,400	31,000
Cyclic									
AVERAGE		2,800	-	2,400	175	0.040	0.027	23,600	35,700
Type E	E1	2,600	-	2,000	163	0.049	0.220	17,700	3,900
(8'-0Hx8'-0L)	E2	2,400	-	2,000	150	0.047	0.189	17,000	4,200
Static									
AVERAGE		2,500	-	2,000	156	0.048	0.205	17,350	4,050
Type E	E1	2,200	-	1,600	138	0.025	0.099	29,300	7,500
(8'-0Hx8'-0L)	E2	2,400	-	2,000	150	0.026	0.104	30,400	7,700
Cyclic									
AVERAGE		2,300	-	1,800	144	0.026	0.102	29,900	7,600

TABLE 2 (CONTINUED)
SUMMARY OF TEST RESULTS

WALL TYPE (PANEL SIZE) LOADING	TEST NO.	TEST LOADS[1] ULTIMATE (lb.)	CODE DEFL. (lb.)	TEARING (lb.)	ALLOWABLE[2] SHEAR STRENGTH (lb./ft.)	DEFLECTION[3] NET (in.)	TOTAL (in.)	SHEAR STIFFNESS[4] NET (lb./in.)	TOTAL (lb./in.)
Type F (8'-0Hx8'-0L) Static	F1	3,600	3,300	2,400	206	0.087	0.109	13,800	11,000
	F2	3,600	3,200	1,800	206	0.079	0.155	15,200	7,700
AVERAGE		3,600	3,250	2,100	206	0.083	0.132	14,500	9,400
Type G (8'-0Hx8'-0L) Static	G1	3,300	3,200	-	200	0.095	0.105	17,600	10,500
	G2	4,500	-	-	281	0.115	0.144	13,000	10,400
AVERAGE		3,900	3,200	-	240	0.105	0.124	12,300	10,500
Type H (8'-0Hx8'-0L) Static	H1	3,000	2,700	2,400	169	0.101	0.186	9.900	5,400
	H2	3,200	2,800	2,600	175	0.089	0.260	12,000	4,100
AVERAGE		3,100	2,750	2,500	172	0.095	0.223	11,000	4,800
Type H (8'-0Hx8'-0L) Cyclic	H1	2,800	-	2,000	175	0.019	0.070	51,600	14,000
	H2	2,200	-	1,400	138	0.008	0.085	98,000	9,200
AVERAGE		2,500	-	1,700	157	0.014	0.078	74,800	11,600

TABLE 2 (CONTINUED)
SUMMARY OF TEST RESULTS

WALL TYPE (PANEL SIZE) LOADING	TEST NO.	TEST LOADS[1] ULTIMATE (lb.)	CODE DEFL. (lb.)	TEARING (lb.)	ALLOWABLE[2] SHEAR STRENGTH (lb./ft.)	DEFLECTION[3] NET (in.)	TOTAL (in.)	SHEAR STIFFNESS[4] NET (lb./in.)	TOTAL (lb./in.)
Type I	I1	3,600	3,400	3,200	213	0.105	0.419	11,400	2,900
(8'-0Hx8'-0L)	I2	3,600	-	3,400	225	0.080	0.225	15,000	5,300
Static									
AVERAGE		3,600	3,400	3,300	219	0.093	0.097	13,200	4,100
Type J	J1	3,400	-	-	213	0.027	0.103	42,000	11,000
(8'-0Hx8'-0L)	J2	3,800	-	-	238	0.017	0.087	74,500	14,600
Static									
AVERAGE		3,600	-	-	225	0.022	0.095	58,250	12,800
Type K	K1	2,200	-	1,200	138	0.054	0.135	13,600	5,400
(8'-0Hx8'-0L)	K2	2,000	-	1,400	125	0.040	0.055	16,700	12,100
Static	K3	2,800	-	1,600	175	0.059	0.085	15,800	11,000
AVERAGE		2,300	-	1,400	146	0.051	0.092	15,400	9,500
Type L	L1	3,400	3,400	2,400	213	0.077	0.137	14,700	3,800
(8'-0Hx8'-0L)	L2	3,400	-	1,800	213	0.091	0.179	12,500	6,300
Static									
AVERAGE		3,400	3,400	2,100	213	0.084	0.158	13,600	7,300
Type M	M1	2,200	2,100	1,800	131	0.070	0.105	10,500	7,000
(8'-0Hx8'-0L)	M2	2,100	2,100	1,400	131	0.073	0.117	9,600	6,000
Static									
AVERAGE		2,150	2,100	1,600	131	0.072	0.111	10,100	6,500

TABLE 2 (CONTINUED)
SUMMARY OF TEST RESULTS

WALL TYPE (PANEL SIZE) LOADING	TEST NO.	TEST LOADS[1] ULTIMATE (lb.)	CODE DEFL. (lb.)	TEARING (lb.)	ALLOWABLE[2] SHEAR STRENGTH (lb./ft.)	DEFLECTION[3] NET (in.)	TOTAL (in.)	SHEAR STIFFNESS[4] NET (lb./in.)	TOTAL (lb./in.)
Type N	N1	4,100	2,900	2,000	181	0.144	0.200	9,500	6,800
(8'-0Hx8'-0L)	N2	4,500	3,100	2,600	194	0.165	0.224	9,100	6,700
Static									
AVERAGE		4,300	3,000	2,300	188	0.155	0.212	9,300	6,800
Type P	P1	2,800	2,500	2,200	156	0.053	0.561	17,600	1,700
(8'-0Hx8'-0L)	P2	3,000	-	2,600	188	0.056	0.568	17,900	1,800
Static									
AVERAGE		2,900	2,500	2,400	172	0.055	0.565	17,800	1,800
Type Q	Q1	2,400	-	2,000	150	0.016	0.492	50,000	1,600
(8'-0Hx8'-0L)	Q2	2,600	-	2,200	163	0.105	0.319	8,300	2,700
Static	Q3	2,400	1,700	2,000	106	0.323	0.179	2,500	4,500
AVERAGE		2,500	1,700	2,100	140	0.148	0.330	20,300	2,900
Type R	R1	3,800	3,300	2,000	206	0.128	0.290	9,900	4,400
(8'-0Hx8'-0L)	R2	3,800	3,500	2,400	219	0.100	0.336	12,700	3,800
Static									
AVERAGE		3,800	3,400	2,200	213	0.114	0.313	11,300	4,100

[1] Test loads are defined as follows:
a) Ultimate load is the maximum load level obtained with displacement measurements recorded
b) Code deflection load is the measured load level corresponding to a drift of 0.5 inches
c) Tearing load is the load level at which tearing or cracking of the sheathing material occurred

[2] Allowable shear strength is the ultimate load obtained divided by panel length and a 2.0 safety factor

[3] Measured deflections at one-third of the ultimate test load level

[4] Shear stiffness determined at one-third of the ultimate test load level

TABLE 3
ALLOWABLE SHEAR FOR WIND OR SEISMIC FORCES
IN POUNDS PER FOOT FOR VERTICAL DIAPHRAGMS OF PLYWOOD, PLASTER, OR GYPSUM BOARD ON STEEL-FRAMED WALL ASSEMBLIES[1]

TYPE OF MATERIAL	MATERIAL THICKNESS	WALL CONSTRUCTION[2] Steel Studs	FASTENER SPACING[3]	ALLOWABLE SHEAR (lbs/ft)	MINIMUM FASTENER SIZE
Gypsum Wallboard (both sides)	1/2"	24" o/c	12"	170	No. 6x1" Bugle Head Screws
	1/2"	16" o/c	12"	215	No. 6x1" Bugle Head Screws
	1/2"	24" o/c	6" Perimeter 12" Interior	280	No. 6x1" Bugle Head Screws
	5/8" Two Ply	24" o/c	Base Ply 24" Face Ply 12"	220	Base Ply No. 6x1" Bugle Head Screws Face Ply No. 6x1-3/8" Bugle Head Screws
Gypsum sheathing board (one side) gypsum wallbd.,opp. side	1/2"	24" o/c	12"	130	No. 6x1" Bugle Head Screws
Construction gd.Inter. plywood,CDX (one side) gypsum wallbd. opp. side	1/2"	24" o/c	12"	190	No. 6x1" Bugle Head Screws
Expanded metal lath and portland cement plaster 3-coat process (both sides)	7/8"	24"o/c	9" (lath)	225	No. 8x1/2"Pan Washer Head Screw (lath)

[1]These vertical diaphragms shall not be used to resist loads imposed by concrete or masonry construction except as allowed in Section 4714(b). Values are for short-time loading due to wind or earthquake and must be reduced 25 percent for normal loading.
[2]Minimum 0.035-inch-thick structural "C" studs attached to minimum 0.035-inch-thick runner track by either No. 10 x 1/2 inch screws or 1/8-inch by 1-inch long fillet welds each side, top and bottom.
[3]Applies to attachment at all studs and runner track.
[4]Uplift of corners to be prevented by clip angles and/or appropriately designed connectors to lower structure.

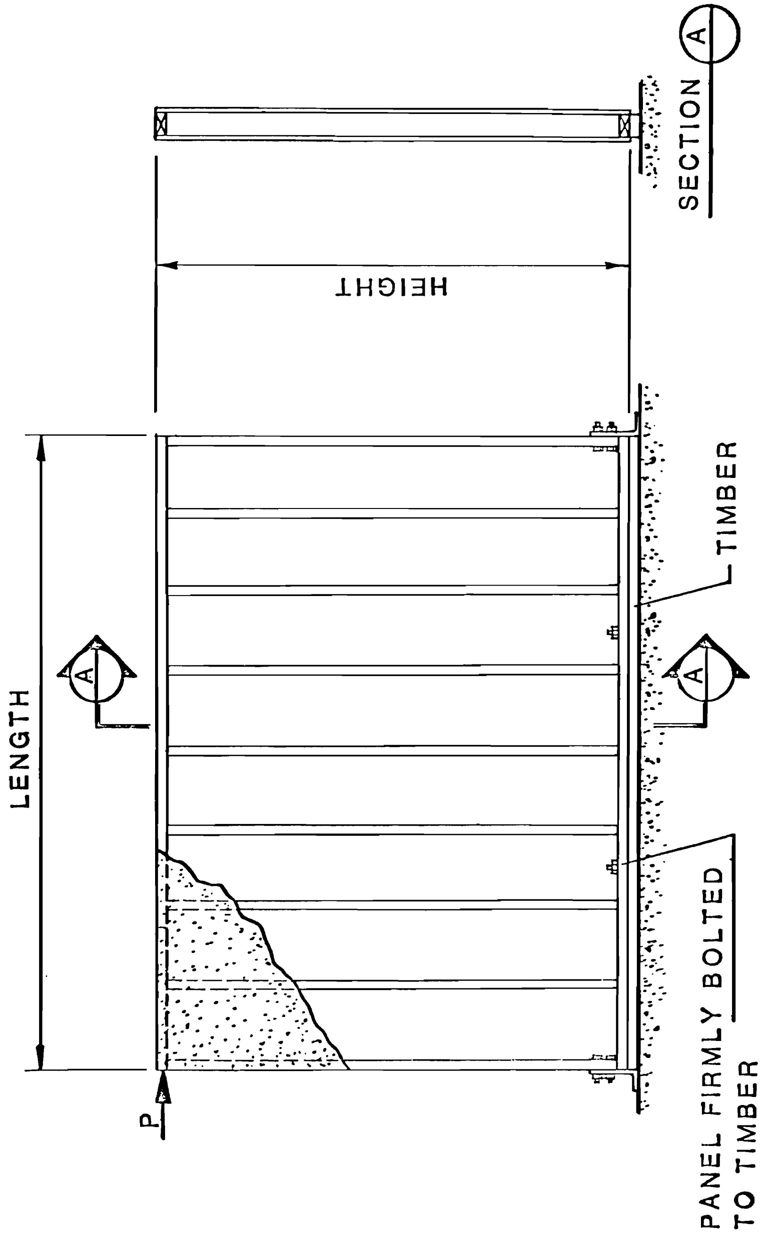


Figure 1. ASTM E564 Rocking Load Wall Assembly

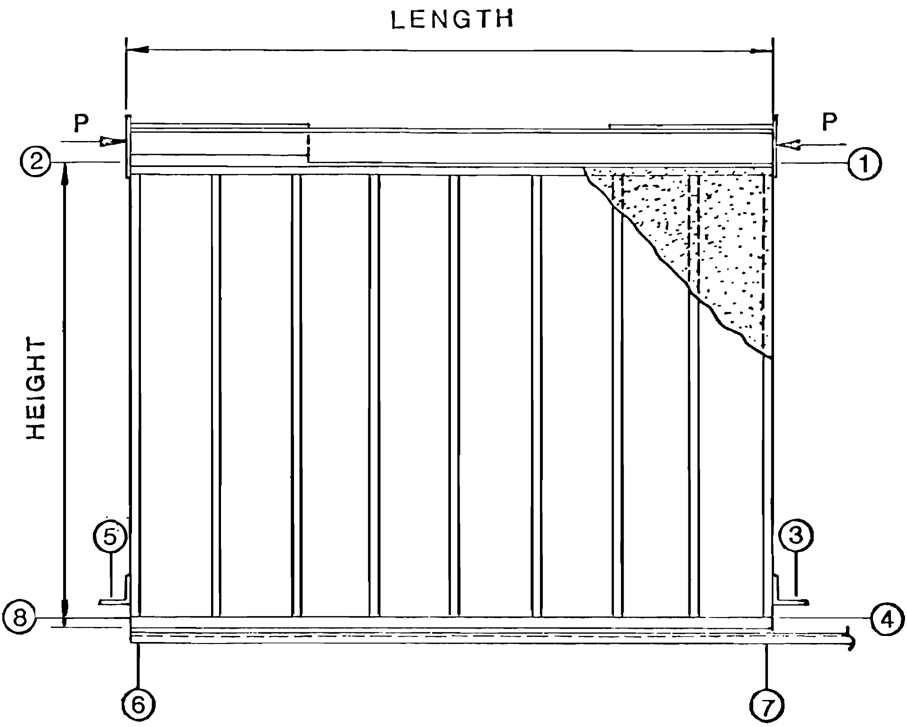


Figure 2. ASTM E564 Wall Assembly Dial Gage Locations

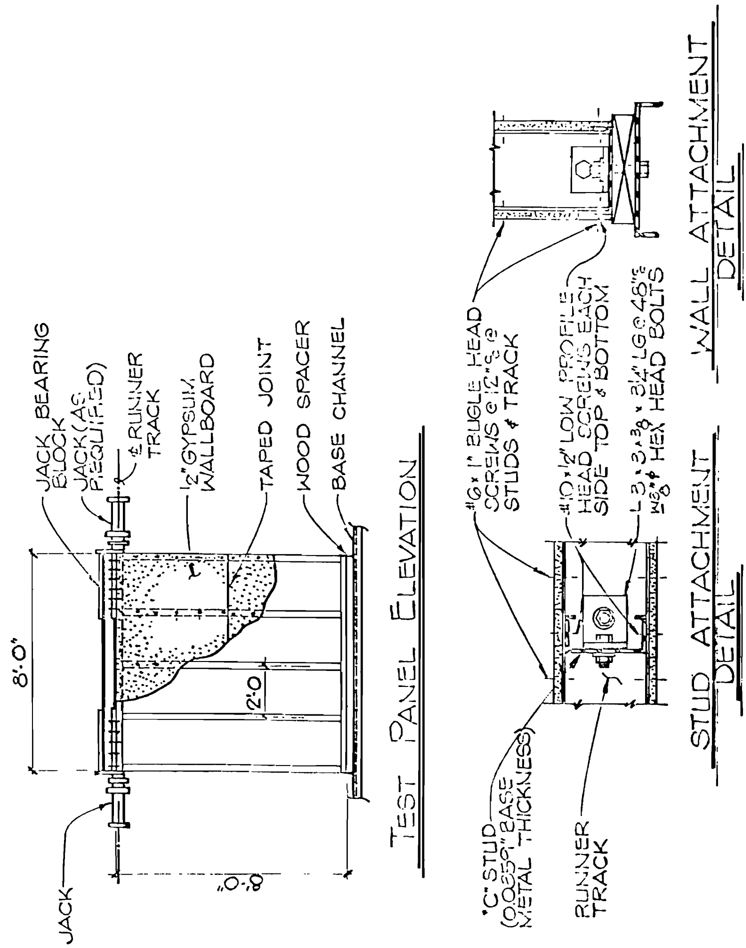


Figure 3. Test Assembly Plan & Details - Wall Type "A"

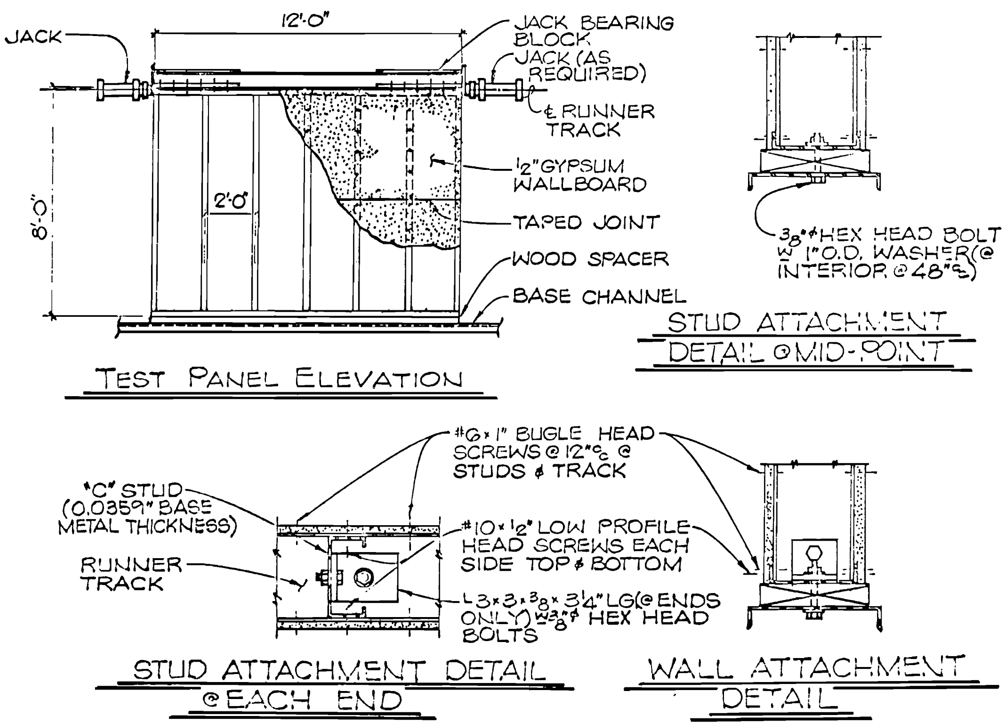


Figure 4. Test Assembly Plan & Details - Wall Type "B"

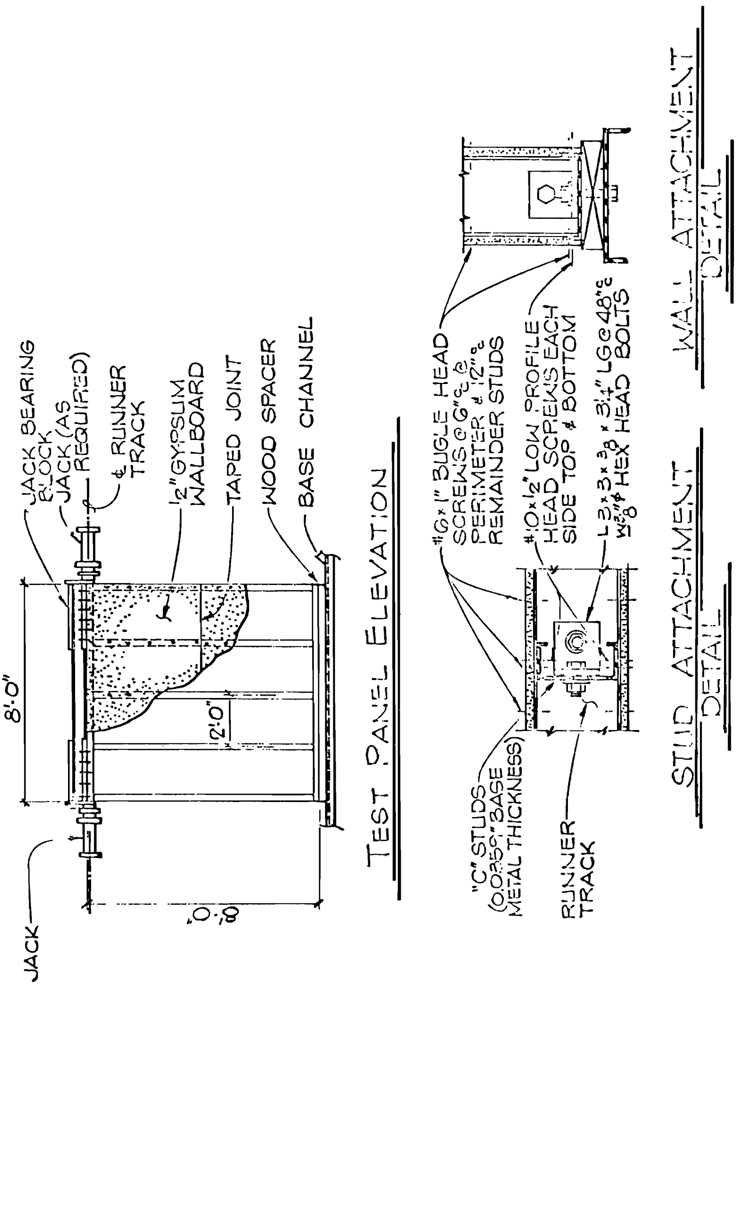


Figure 5. Test Assembly Plan & Details - Wall Type "C"

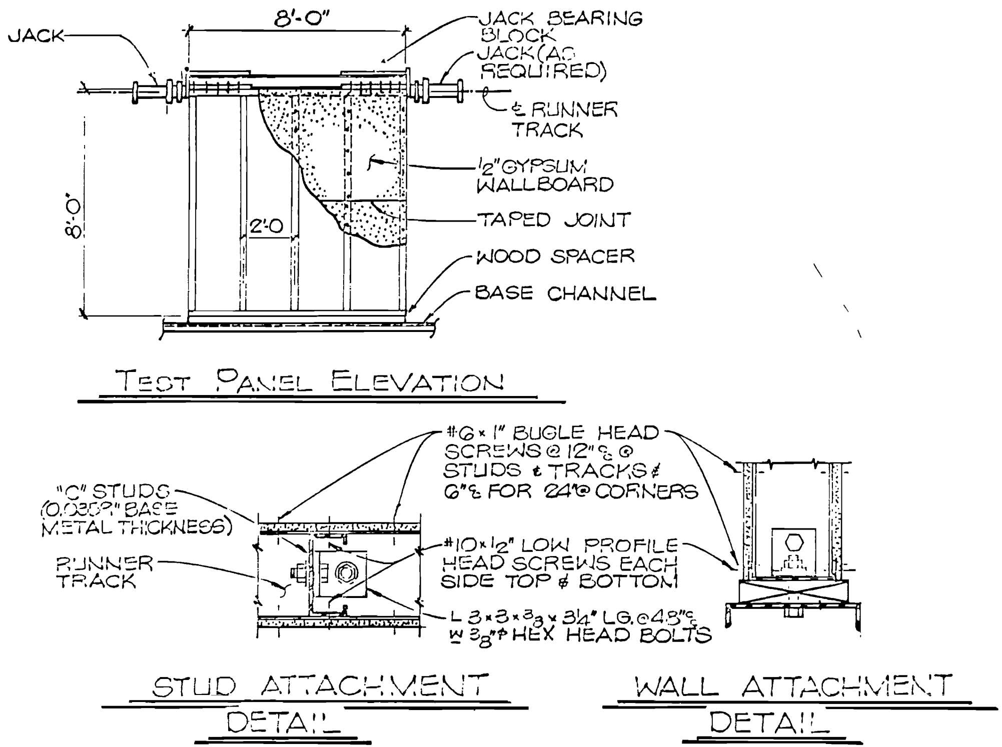


Figure 6. Test Assembly Plan & Details - Wall Type "D"

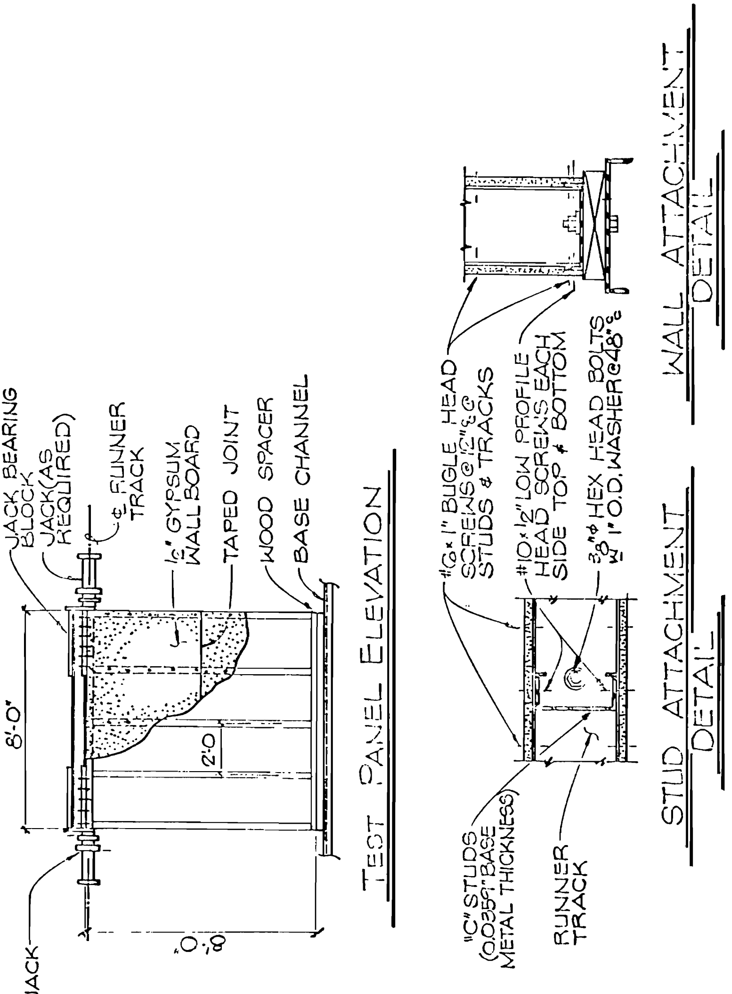


Figure 7. Test Assembly Plan & Details - Wall Type "E"

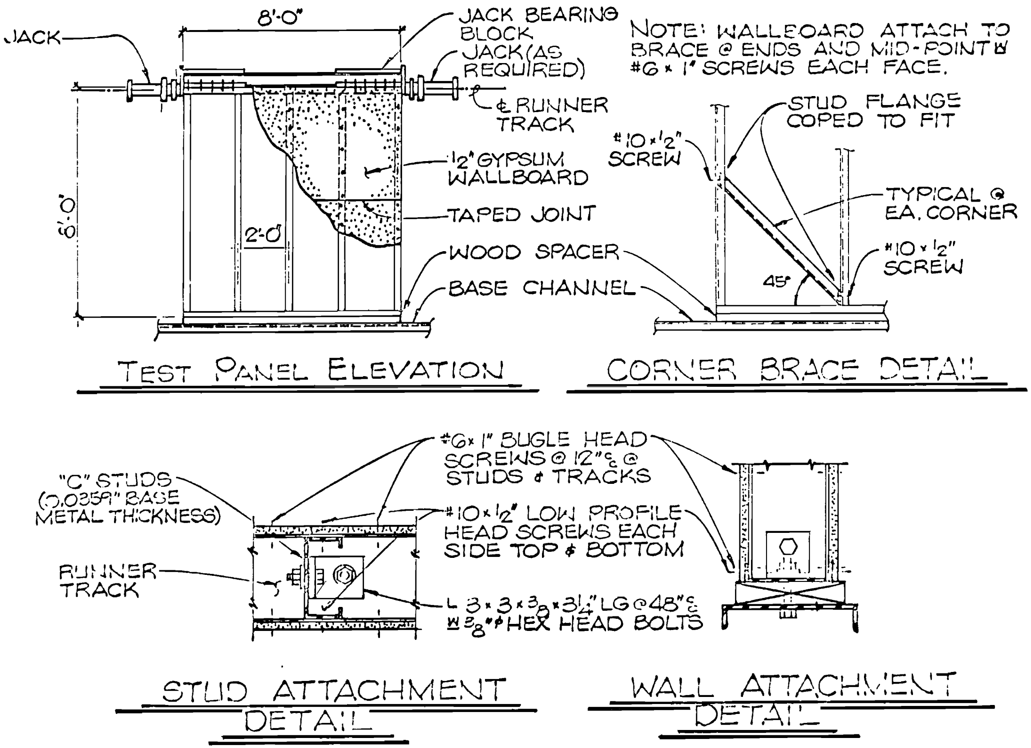


Figure 8. Test Assembly Plan & Details - Wall Type "F"

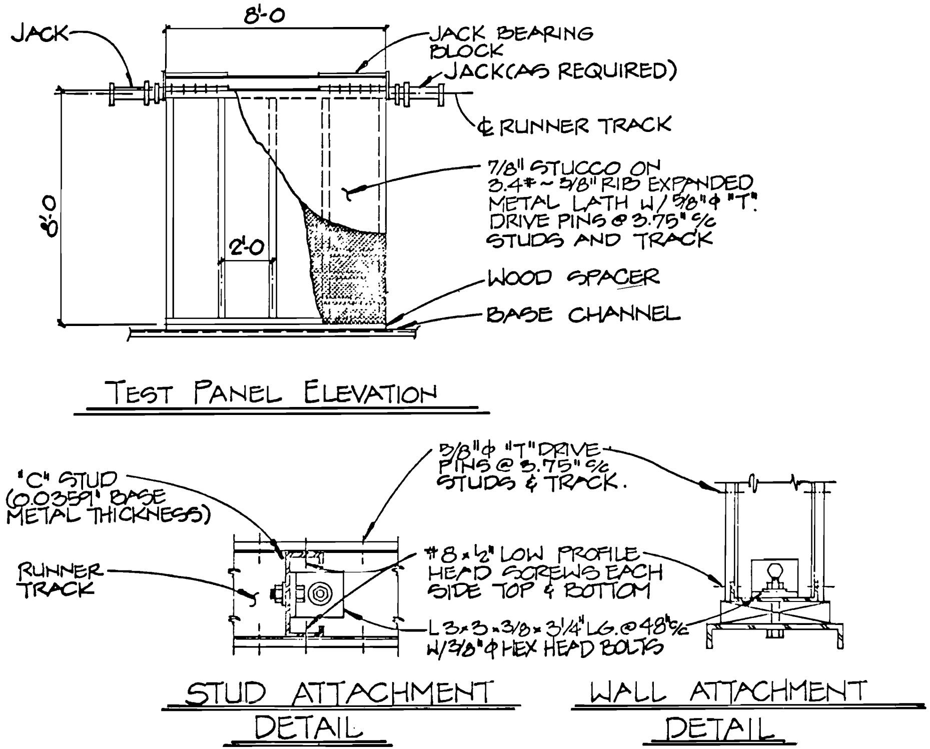


Figure 9. Test Assembly Plan & Details - Wall Type "G"

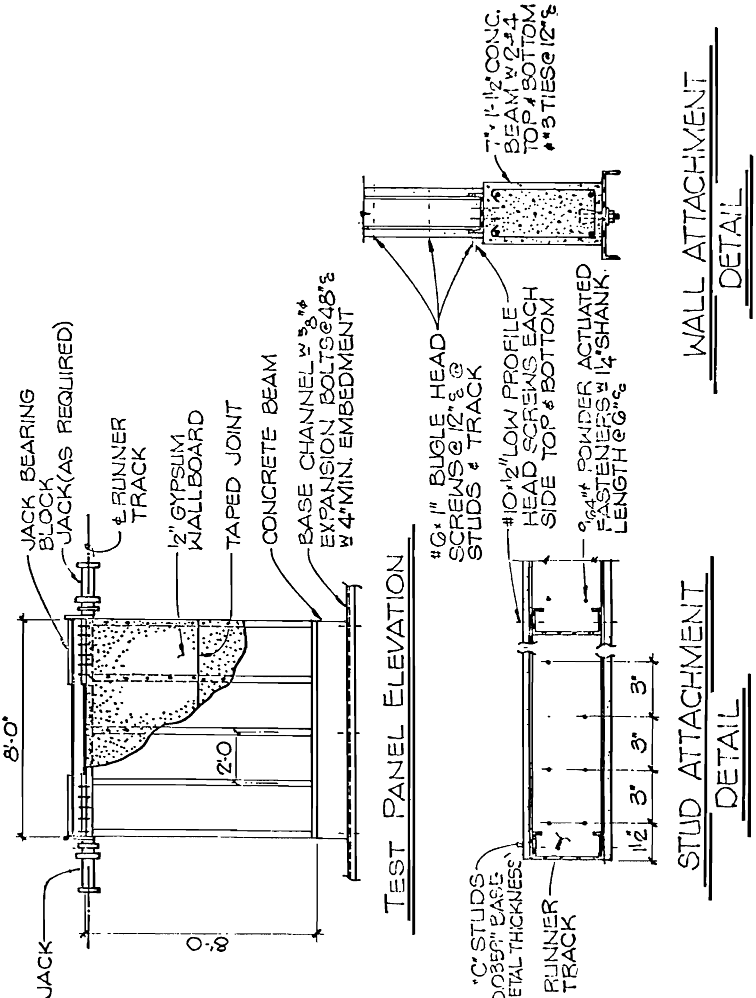


Figure 10. Test Assembly Plan & Details - Wall Type "H"

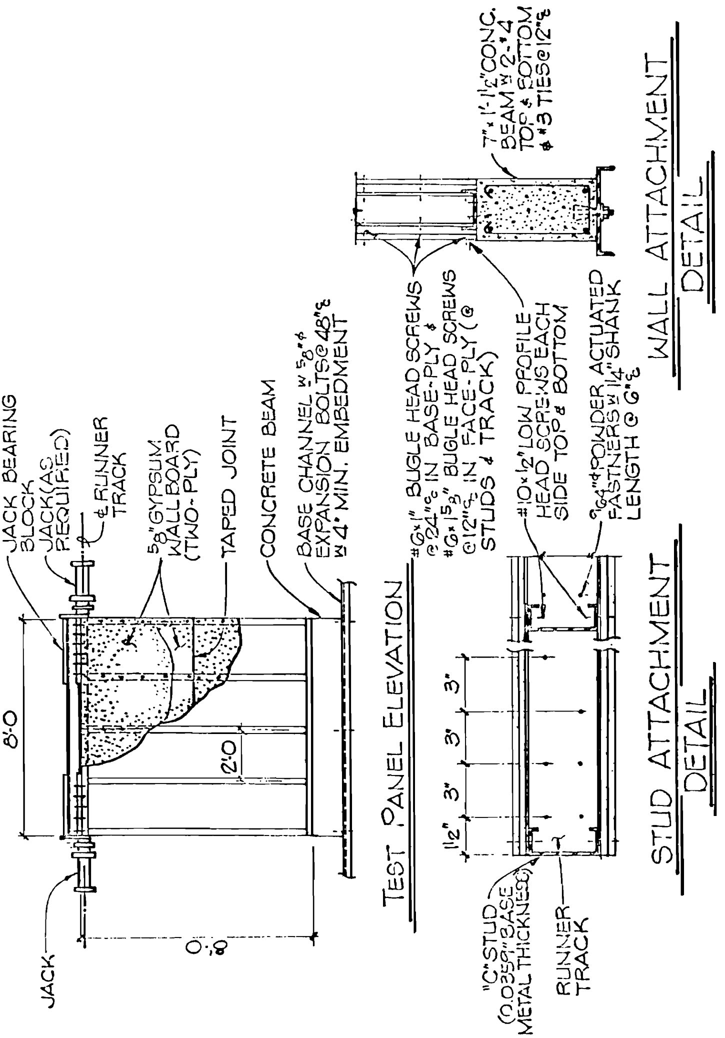


Figure 11. Test Assembly Plan & Details - Wall Type "I"

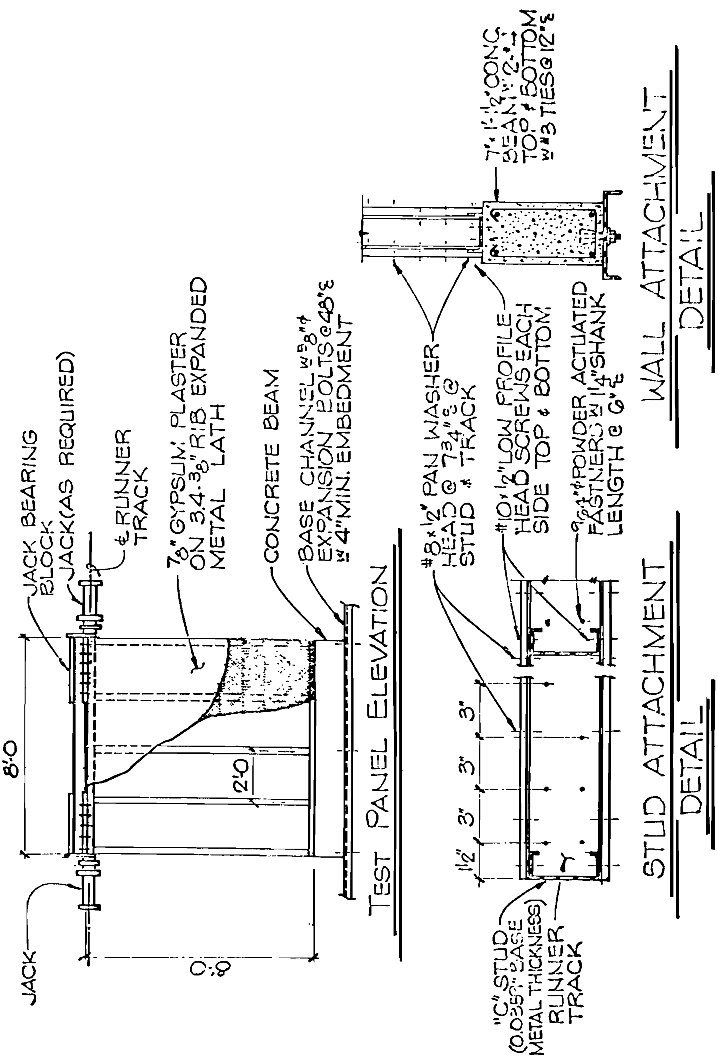


Figure 12. Test Assembly Plan & Details - Wall Type "J"

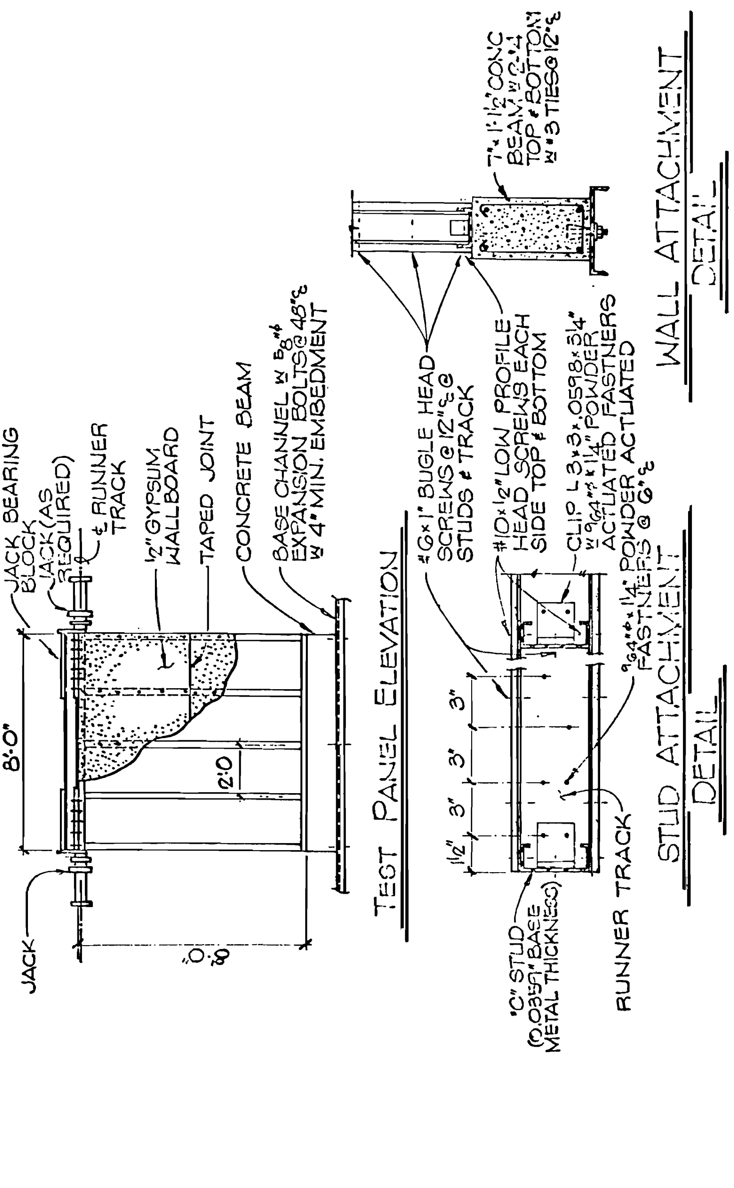


Figure 13. Test Assembly Plan & Details - Wall Type "K"

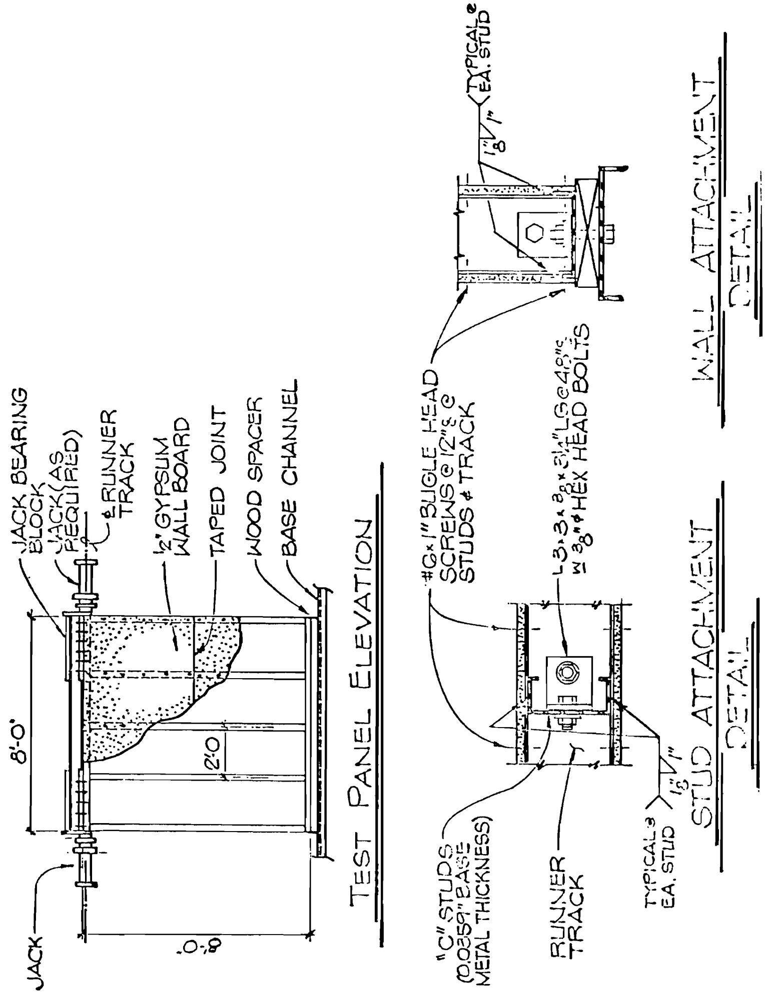


Figure 14. Test Assembly Plan & Details - Wall Type "L"

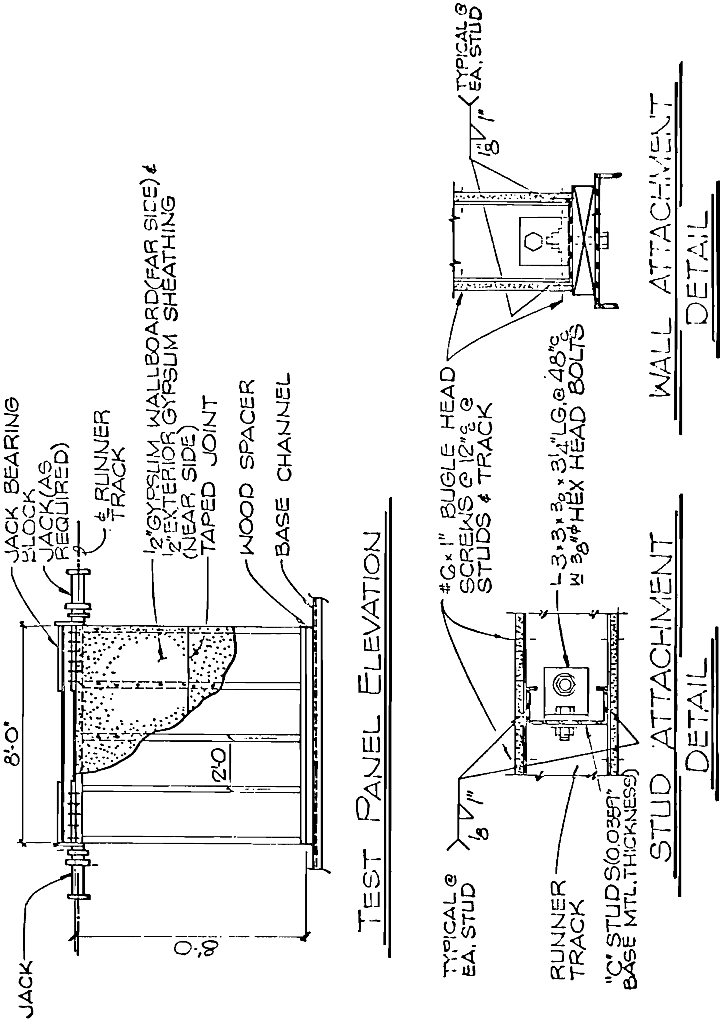


Figure 15. Test Assembly Plan & Details - Wall Type "M"

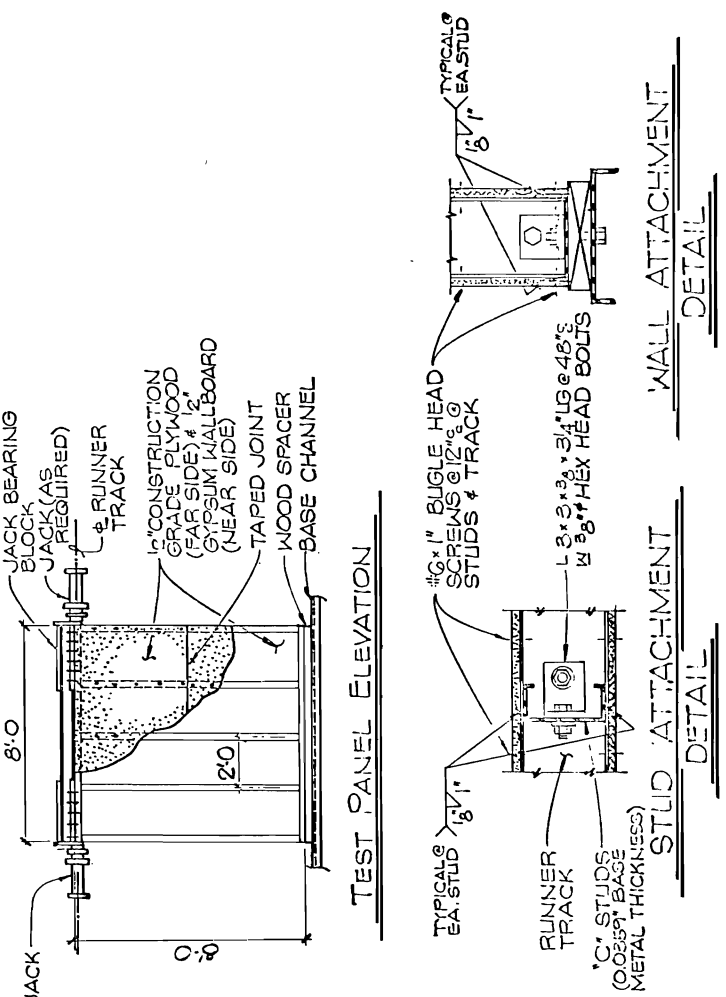


Figure 16. Test Assembly Plan & Details - Wall Type "N"

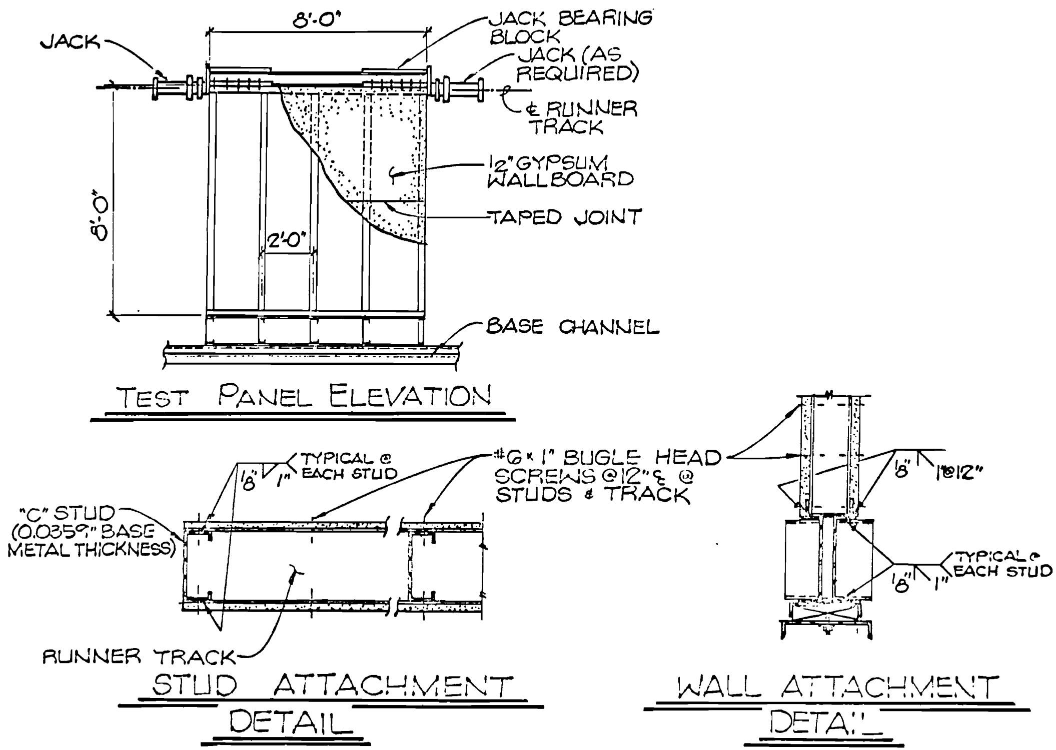


Figure 17. Test Assembly Plan & Details - Wall Type "P"

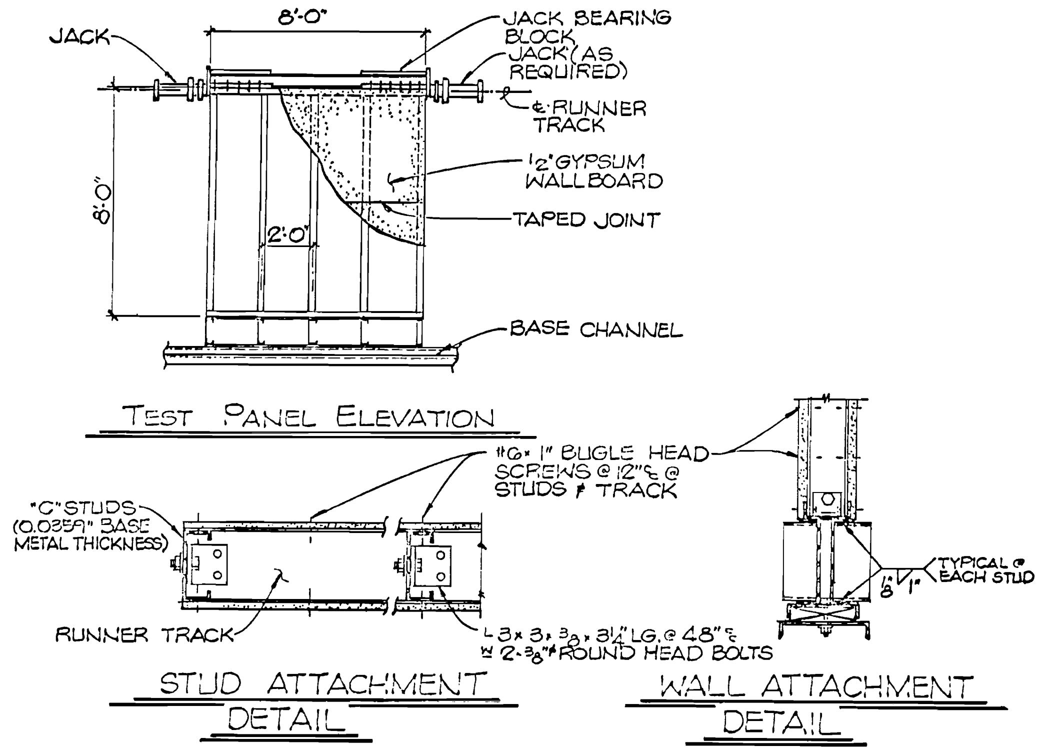


Figure 18. Test Assembly Plan & Details - Wall Type "Q"

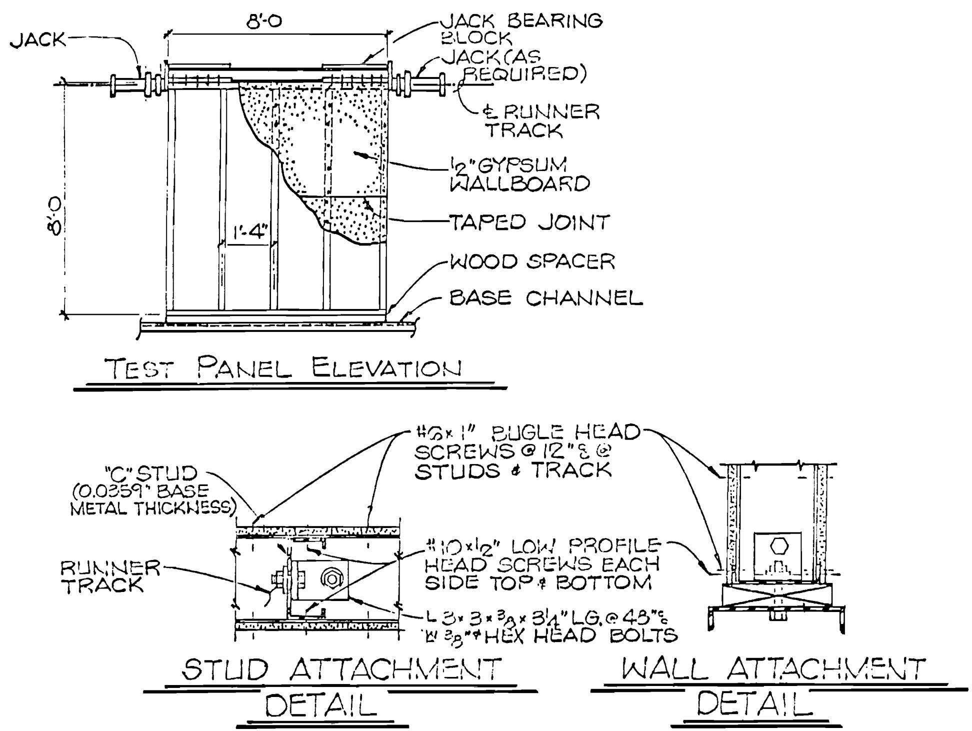


Figure 19. Test Assembly Plan & Details - Wall Type "R"

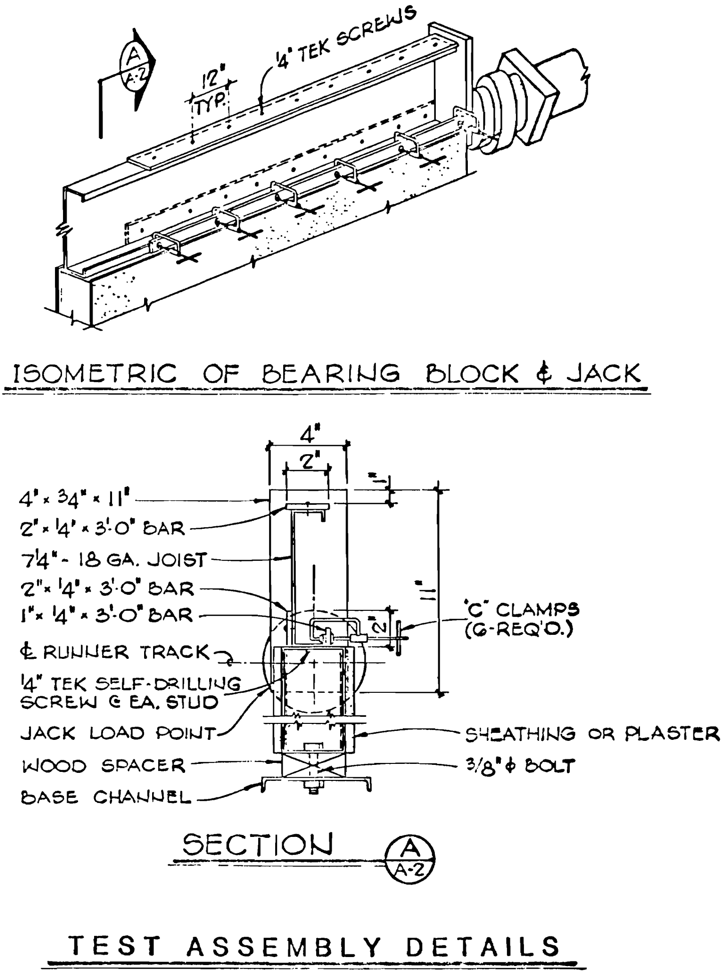
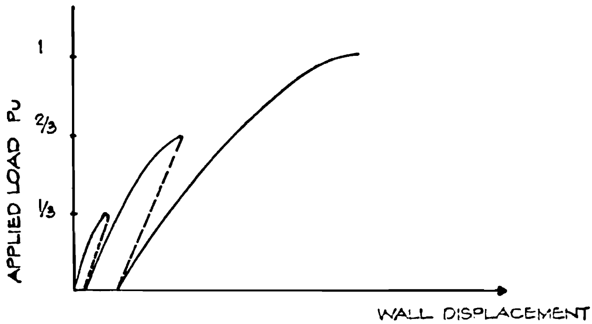
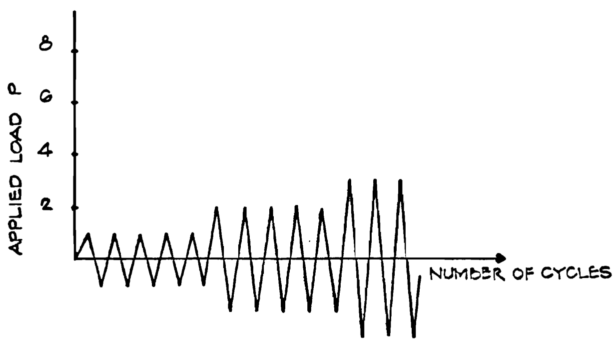


Figure 20. Test Assembly Details



a) Static Loading



b) Cyclic Loading

Figure 21. Loading Sequence